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Original Research

Effect of mineral admixture on the properties of engineered cementitious composite

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ABSTRACT

Engineered cementitious composites are a new kind of fiber-reinforced cementitious composite that exhibits superior performance. They may be used to reduce maintenance and repair costs, extend the service life of buildings, and overcome ordinary concrete's lack of bendability. The purpose of this study was to determine the effect of replacing cement with up to 10% silica fume on the characteristics of Engineered Cementitious Composites concrete with a binder concentration of 1000 kg/m3 and two kinds of fiber (steel and carbon). Numerous experiments were conducted to determine the behavior of Engineered Cementitious Composites concrete, including compressive strength for (cubes and cylinders), tensile strength for splitting, flexural strength, and load-bearing capacity (when slabs at simply supported and fixed). The experimental findings indicated that up to 10% substitution of silica fume for cement increased the compressive strength of this kind of concrete after 28 days. Other parameters such as splitting tensile strength, flexural strength, and load-bearing capacity exhibited the similar pattern.

Keywords: Carbon fiber, engineered cementitious composites, Load displacement curve, Silica fume, Steel

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1. Introduction

Owing to the minimal expense and widespread of raw constituents, concrete has been the prevalent construction material throughout the last century. Although it has several advantages considerable problems can occur. These problems are consequent to the cracking and brittleness of concrete. The foremost problem of structural performance in safety, sustainability, and durability is the brittleness of concrete [1].

The deficiency of bendability is a main reason for failure beneath strain and has been an imperative factor in the enhancement of an elegant material, bendable concrete also recognized as Engineered Cementitious Composites (ECC), which is accomplished to reveal significantly improved flexibility [2].

ECC was developed in the early 1990s using low-toughness mortar and polymeric fibers and is based on micromechanics theory [3]. ECC is prepared from similar fundamental constituents of normal concrete but with adding superplasticizer which is essential to convey the desired workability. Nevertheless, coarse aggregates are not utilized in ECCs with high powder content. Fly ash, silica fume, and blast furnace slag are indications of cementitious materials that may be utilized to increment the paste content [2].

ECC is a novel kind of high-performance fiber-reinforced cementitious composite designed to give high ductility beneath mechanical loading, comprising shear and tensile loadings [4]. Though the mixed proportions of ECC have been well recognized, only insufficient laboratory works and veteran researchers have constantly reproduced ECC with high ductility [4].

The properties of ECC in compressive are not considerably altered from conventional to high strength concrete. ECC has a compressive strength varies from (30 to 90) MPa. With a modulus of elasticity between (20 to 25) GPa normally lower than concrete owing to the non-attendance of coarse aggregates, but with slightly higher compressive strain capacity about 0.45-0.65% [5].

After first cracking, ECC behaves similarly to a ductile metal, with a strain capacity up to 500 times that of regular concrete. Even when subjected to considerable mandatory deformation, ECC crack widths remain less than (60 m). this type of concrete holds substantial promises to resolve the serviceability issues associated with concrete members (RC) structures, because of its inherency to small crack width and high tensile ductility [6].

ECC may help prolong the life of buildings and reduce repair and maintenance costs. At the moment, ECC is being used in a range of applications, including ECC link slabs on bridge decks and ECC coupler beams in multistory structures to increase the earthquake performance of certain concrete repair applications [7].

Once the first restricted fracture is created at its tensile strength, ordinary concrete fails in a brittle manner. Nonetheless, following first breaking, ECC's tensile load capacity continues to increase under uniaxial stress. The formation of numerous fractures complements the strain-hardening tendency. Each fracture steadily expands to a certain width, and increased stress results in the creation of more cracks. This technique enables ECC member cracking to achieve a saturated condition with a limited crack width and opening, as dictated by the matrix fibers' stress transmit capability. [8].

According to Ding et al.[9], improving the tensile properties of ECC can help to improve the mechanical properties of the material, particularly its ductility. They also stated that the primary criterion for lining failure in tensile stress in the lining cross- section, which is then influenced by ECC's super high toughness and crack resistance, as well as its crack control capability. Furthermore, the deformation execution of the ECC lining is greater than those of normal and RC linings.

ECC strain-hardening behavior was demonstrated by Guan et al.[10]. The first cracking strength was 2.9 MPa, and the ultimate tensile strength was 4.4 MPa, whereas the tensile strain capacity was 4.5%. Moreover, they inscribed that the localized cracking could penetrate the composite beam cover. The cracking widths were 98 and 115 μm for with and without fiber reinforcements.

Mohammedameen et al. [11] concluded that ECC with carbon fiber-reinforced polymer (ECC-CFRP) have superior behavior compared to ECC with basalt fiber-reinforced polymer (ECC-BFRP) when subjected to a 3.5% seawater environment. ECC-CFRP had a higher degree of ductility and mechanical performance than ECC-BFRP, according to the results.

2. Experimental work

2.1. Materials

In this study, ordinary Portland cement (OPC) according to Iraqi standard No.5/1984 [12] and silica fume (SF) conforming to ASTM C 618 [13] were used. Table 1 summarizes some of the physical attributes and chemical compositions of OPC and SF.

Natural fine aggregate from the Al-Ekhadir area was used. It sieved through a 2.36 mm mesh size sieve and had a specific gravity of 2.65. The desired workability of the mixtures was achieved with the use of a type F superplasticizer (SP) that adhered to ASTM C494 [14]. As seen in Figure 1, this study used two kinds of fibers: steel and carbon fiber. Straight steel fibers with defined qualities are provided in Table 2, while carbon fibers with a 6 mm length with specified properties are listed in Table 3.

Table 1. Chemical analysis of OPC and SF

Oxide.	OPC (%)	SF (%)
Silica, SiO_2	20.18	85
Alumina, Al_2O_3	5.00	2.71

Oxide.	OPC (%)	SF (%)
Iron Oxide, Fe_2O_3	3.60	1.31
Lime, CaO	62.21	0.45
Magnesia, MgO	2.31	0.55
Sulfate, SO_3	1.44	0.41
Na_2O	----	0.45
K_2O	----	1.52
Loose on ignition, L.O.I	3.29	6

Table 2. Chemical analysis of OPC and SF

Properties	Results
Ultimate tensile strength	2600 MPa
Young's Modulus	200000MPa
Relative density	7800 kg / m^3
Length	13 mm
Diameter	0.2 mm
Aspect ratio (l/d)	65

Table 3. Properties of carbon fiber

Properties	Results
Tensile Strength	165 MPa
Flexural Strength	259 MPa
Filament Diameter	7 µm
Filament Length	6 mm
Elongation	1.5%
Bulk Density	425 g/L

Figure 1. Steel and carbon fibers

2.2. Mix proportions

In this research work, six mixes with a binder content were used (cement + silica fume) of 1000 kg/m3 with a 0.2 water to binder ratio (w/b). The replacement of silica fume was (0, 5, and 10) % of cement weight. Two types of fiber were used steel and carbon fiber with the percent of the fiber used being 1% of the volume of ECC mix with 3.5% of SP. The mix proportions are listed in Table 4.

Table 4. Mix proportions of ECC mixes

Mix	Cement (Kg/m^3)	Silica Fume (Kg/m^3)	Steel Fiber (Kg/m^3)	Carbon Fiber (Kg/m^3)	Fine aggregate (Kg/m^3)
S0	1000	0	78.5	0	1115.7
S5	950	50	78.5	0	1098
S10	900	100	78.5	0	1080.3
C0	1000	0	0	18	1115.7

Mix	Cement (Kg/m^3)	Silica Fume (Kg/m^3)	Steel Fiber (Kg/m^3)	Carbon Fiber (Kg/m^3)	Fine aggregate (Kg/m^3)
C5	950	50	0	18	1098
C10	900	100	0	18	1080.3

2.3. Mixing, casting, and curing

To blend ECC mixtures, a mixer with a mixing speed of (470 rpm) was utilized. The dry ingredients (cement, SF, and sand) were first combined for three minutes at a slower speed of (100 rpm). Following that, half of the dry ingredients were added and the mixture was stirred for 3 minutes. The remaining water and SP were added to the mix and mixed at a high speed for (3) minutes. Finally, the fiber (steel / carbon) was added to the mix and continued to be mixed at a high speed for (2) minutes. Following that, new concrete was poured into the molds and compacted with the help of a vibrating table. Following that, the molds were covered with nylon sheets and allowed to air dry for 24 hours. Following that, concrete specimens were taken from the molds and cured in (22 2) oC water until the age of the test was reached (28 days).

3. Results and discussions

3.1. Compressive strength

This test was accomplished on two types of samples 100 mm cubes according to BS 1881 : Part 116 [15] and 150*300 mm cylinders according to ASTM C39 [16]. The average of three specimens was taken for each mix (18 cubes and 18 cylinders). The results indicated that the compressive strength improved with increasing the replacing level of cement by silica fume up to 10%. The increase reached (1.64 and 1.55) % for the cube while, it was (1.37 and 2.05) % for cylinder both percentages for mixes containing steel and carbon fiber respectively Figure 2. This is can be attributed to the pozzolanic reaction between silica fume and Ca(OH)2 and producing additional C–S–H gel at the final stages [17]. The outcomes also revealed that for the same replacing level of silica fume, the mix containing carbon fiber gives higher compressive strength compared with the mix containing steel fiber.

The results also revealed that there was a relationship between cube and cylinder samples, in general, the ratio of 100mm cube compressive strength/ 150mm cylinder compressive strength was about (1.024 and 1.027) for steel and carbon fiber respectively.

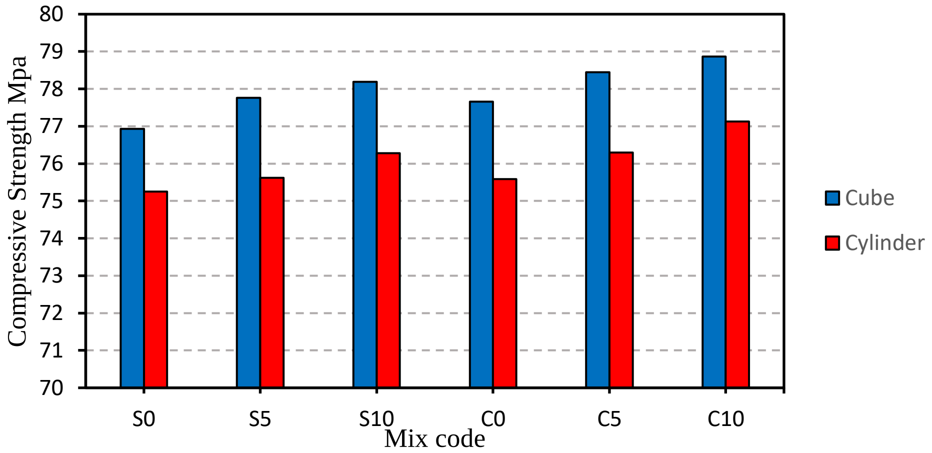

Figure 2. Compressive strength of ECC concrete

3.2. Splitting tensile strength

This test was done on 150*300 mm cylinder affording to ASTM C496 [18]. An average of 3 samples was taken for each mix. The results showed that increasing the percentage of cement replaced by silica fume increased the tensile strength by up to 10%. The increasing reached to (7.28 and 17.62 %) for the mixes containing steel and carbon fiber respectively Figure 3. The results also indicated that for the same replacing level of silica fume, the mix containing carbon fiber gives higher splitting tensile strength compared with the mix containing steel fiber.

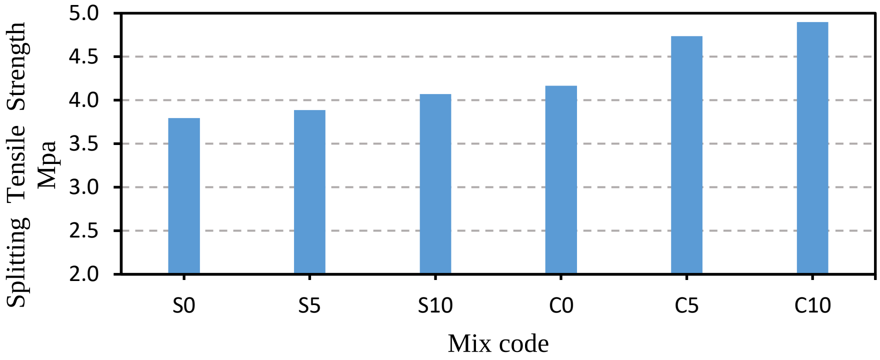

Figure 3. Splitting tensile strength of ECC-concrete

3.3. Flexural strength

The strength of flexural test was done according to ASTM C 78 [19] on 100×100×500 mm prisms. For each mix, an average of three samples was taken. The flexural strength test results revealed that increasing the percentage of cement replaced by silica fume up to 10% improved the flexural strength. The increasing reached to (9.73 and 17.47 %) for the mixes containing steel and carbon fiber respectively as revealed in Figure 4. The outcomes also revealed that for the same replacing level of silica fume, the mix containing carbon fiber gives higher flexural tensile strength compared with the mix containing steel fiber.

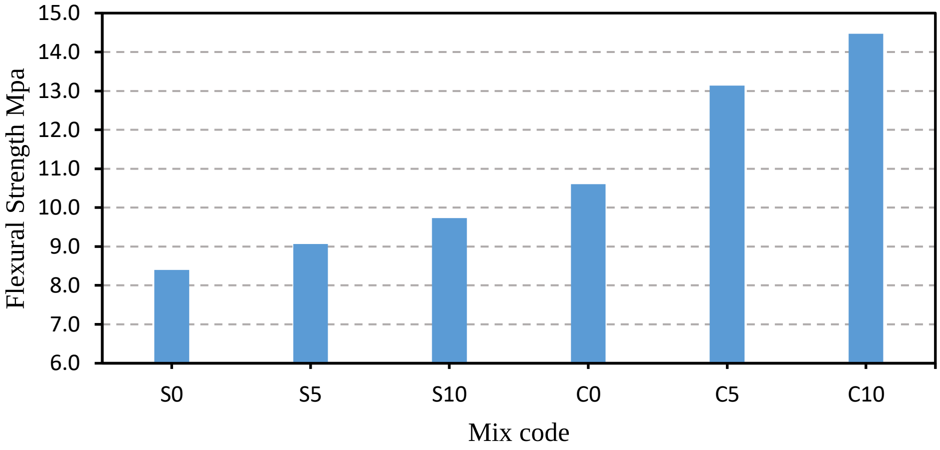

Figure 4. Flexural strength of ECC concrete

3.4. Load-displacement curve

The load- displacement test was performed by taking the average of three specimens of panels (total of 18) of (400*400*50) mm using two types of tests. The first one uses simply supported and the second uses fixed supported panels. The central displacement was measured at the center of the panels, by using a dial gauge of (0.01mm) accuracy with (25mm) capacity as shown in Figure 5.

The results of simply and fixed supported showed that the load -carrying capacity increased with increasing the silica fume replacement as illustrated in Figures 6 and 8 also, it can be recognized that the displacement of panels was less when they fixed for carbon and steel fiber but, the load capacity until failure was an increase when the panels were simply supported.

Also, from Figures 7 and 9 which were shows cracking pattern for simply and fixed supported panels for steel and carbon fiber, it can be seen that the panels were separated into two parts when simply supported but, when the steel fiber was 0 and 5% the panels separated into four pieces when they were fixed support while, when the steel fiber was 10% the panels remains one unit; however for panels with carbon fiber they were remains as one unit until failure for all ratios of carbon; and Table 5 supports this relationship. Through the table, it appears that the displacement decreases with an increase in the number of fibers. We also note that the fixed panels have displacement of approximately half of the simply supported samples.

The results also indicated that for the same percentage of silica fume the samples containing carbon fiber give higher displacement compared to corresponding samples containing steel fiber.

Figure 5. Dial gauge

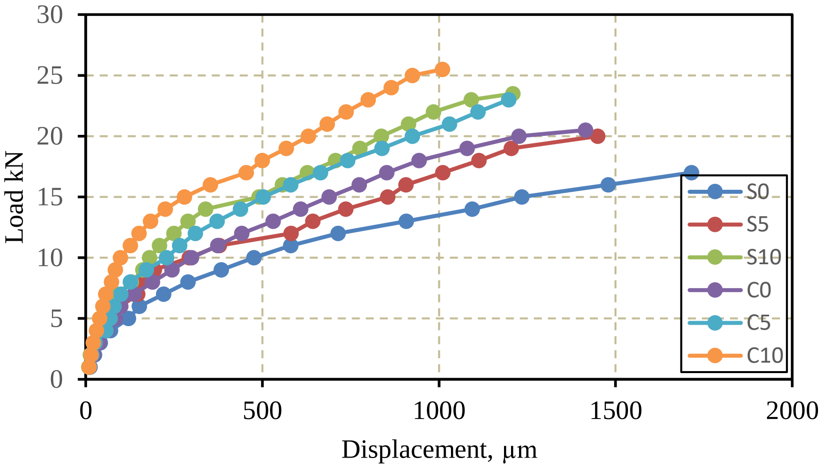

Figure 6. Load-displacement curves of simply supported ECC concrete for steel and carbon fiber

Figure 7. Cracking pattern of simply supported ECC concrete

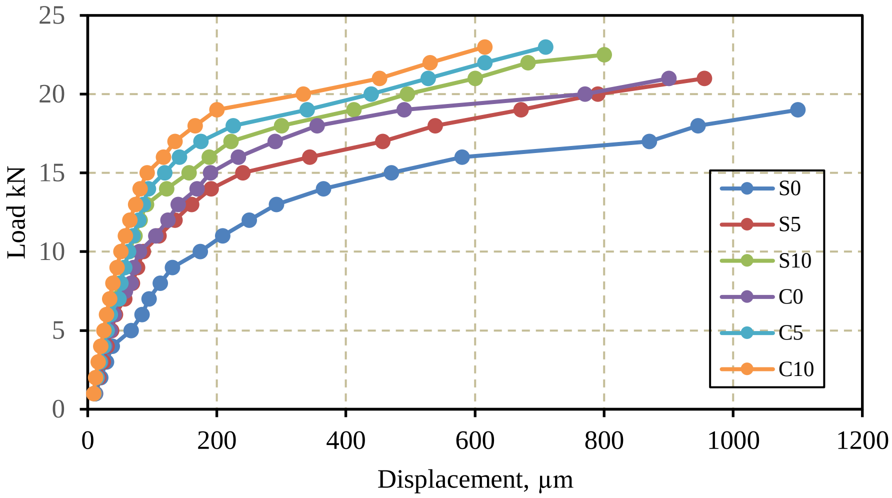

Figure 8. Load-displacement curves fixed supported of ECC concrete for steel and carbon fiber

Table 5. Displacement at first crack load

Mix	Simply supported		Fixed supported	
	First Crack Load (kN)	Displacement at first crack load (µm)	First Crack Load (kN)	Displacement at first crack load (µm)
S0	5.0	121	6.0	67
S5	6.5	110	7.0	57
S10	7.0	90	8.0	49
C0	6.0	100	7.5	58
C5	7.0	82	8.0	51
C10	8.0	73	9.0	45

Figure 9. Cracking pattern of fixed supported ECC concrete for steel and carbon fiber

4. Conclusions

In view of the results of this work it can be seen that:

1. Replacing of cement by silica fume up to 10% improved the compressive strength of ECC concrete at 28 days. The increment reached to (1.64 and 1.55 %) for the cube and (1.37 and 2.05) for the cylinder for mixes containing steel and carbon fiber respectively.
2. The same behavior can be seen for splitting tensile strength the increasing reached to (9.73 and 17.47 %) for the mixes containing steel and carbon fiber respectively.
3. Flexural strength enhanced by the addition of silica fume up to 10% at age of 28 days. It showed an increase of about (9.73 and 17.47 %) for the mixes containing steel and carbon fiber respectively.
4. The results of the load-displacement curve showed that the displacement decreased with increasing the replacement of silica fume. The results also indicated that for the same percent of silica fume the samples containing carbon fiber gives higher displacement compared to corresponding samples containing steel fiber.
5. The results also, showed that the panels with fixed support have less displacement and load applied to failure compared to simply supported panels.
6. All simply supported panels separated into two parts when failed while, the fixed panels when subjected to the load, panels with 0 and 5% steel fibers separated into several parts, while the rest of panels kept their shape and did not separate into pieces upon failure.

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